

NAVAL POSTGRADUATE SCHOOL MONTEREY, CALIFORNIA



THESIS



**COST EFFECTIVENESS ANALYSIS COMPARING
TWO MEDICAL IMAGING TECHNOLOGIES**

by
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June 1995

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DTIC QUALITY INSPECTED 1

REPORT DOCUMENTATION PAGE			Form Approved OMB No. 0704	
Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instruction, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the office of Management and Budget, Paperwork Reduction Project (0704-0188) Washington DC 20503.				
1. AGENCY USE ONLY (Leave Blank)	2. REPORT DATE June 1995	3. REPORT TYPE AND DATES COVERED Master's Thesis		
4. TITLE AND SUBTITLE COST EFFECTIVENESS ANALYSIS COMPARING TWO MEDICAL IMAGING TECHNOLOGIES		5. FUNDING NUMBERS		
6. AUTHOR(S) Tracey L. Syvertson				
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Naval Postgraduate School Monterey CA 93943-5000		8. PERFORMING ORGANIZATION REPORT NUMBER		
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)		10. SPONSORING/MONITORING AGENCY REPORT NUMBER		
11. SUPPLEMENTARY NOTES The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government.				
12a. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release; distribution is unlimited.		12b. DISTRIBUTION CODE		
13. ABSTRACT (maximum 200 words) The decreasing Federal budget and increasing demand for quality healthcare warrants using cost effective state-of-the-art technology in Department of Defense medical treatment facilities. The purpose of this thesis is to compare state-of-the-art digital imaging with conventional film-based imaging technology at two Army Medical Centers. The baseline activity for the study was Fitzsimons Army Medical Center and the digital alternative used was Madiagan Army Medical Center. The Medical Digital Imaging Support (MDIS) has been operational at Madigan, the first DoD facility to use the equipment, since early 1992. The MDIS system is a network that links several imaging modalities within and between medical treatment facilities. This study focuses on the physician, the primary user of the system. Physician questionnaire respondents felt that digital imaging reduces the amount of retakes, significantly reduces the number of images lost, and decreases the amount of time to retrieve an archived image from the storage unit. Using the Tri-Tac methodology, the cost effectiveness calculation determines that digital imaging technology is 2.54 more effective per capital investment dollar than the traditional film-based technology.				
14. SUBJECT TERMS Digital Imaging, Telemedicine, Cost Effectiveness Analysis, Radiology Systems, Medical Digital Imaging Support (MDIS), Tri-Tac Methodology		15. NUMBER OF PAGES 62		
		16. PRICE CODE		
17. SECURITY CLASSIFICATION OF REPORT Unclassified	18. SECURITY CLASSIFICATION OF THIS PAGE Unclassified	19. SECURITY CLASSIFICATION OF ABSTRACT Unclassified	20. LIMITATION OF ABSTRACT UL	

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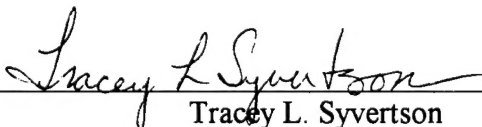
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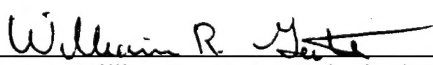
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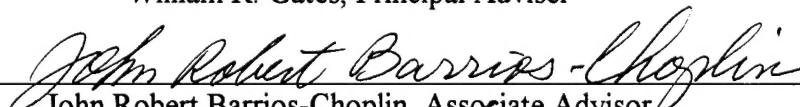
MASTER OF SCIENCE IN MANAGEMENT

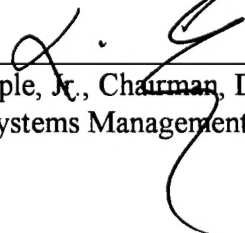
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ABSTRACT

The decreasing Federal budget and increasing demand for quality healthcare warrants using cost effective state-of-the-art technology in Department of Defense medical treatment facilities. The purpose of this thesis is to compare state-of-the-art digital imaging with conventional film-based imaging technology at two Army Medical Centers. The baseline activity for the study was Fitzsimons Army Medical Center and the digital alternative used was Madiagan Army Medical Center. The Medical Digital Imaging Support (MDIS) has been operational at Madigan, the first DoD facility to use the equipment, since early 1992. The MDIS system is a network that links several imaging modalities within and between medical treatment facilities. This study focuses on the physician, the primary user of the system. Physician questionnaire respondents felt that digital imaging reduces the amount of retakes, significantly reduces the number of images lost, and decreases the amount of time to retrieve an archived image from the storage unit. Using the Tri-Tac methodology, the cost effectiveness calculation determines that digital imaging technology is 2.54 more effective per capital investment dollar than the traditional film-based technology.

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I. INTRODUCTION

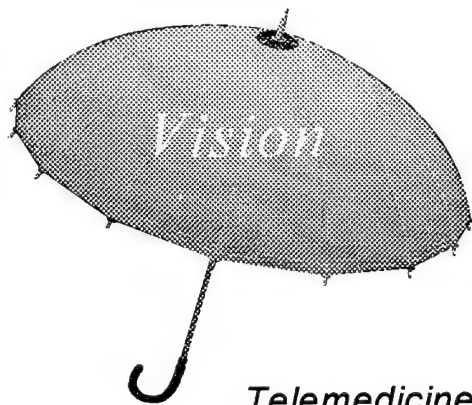
A. GENERAL BACKGROUND

As the 21st century approaches, the Government is reforming the national health care system. The goals of the reform initiative begin with "managed care" and better access to health care for citizens. Striving to meet these goals and incorporating many lessons learned in the 1980s, the Department of Defense created the "Gateway to Care Program." The goal of the program was to give hospital commanders more power to treat military health care beneficiaries by creating local physician networks to meet the needs of the supported population. Health care in the military has experienced many changes in the 1990s and will continue to change even more rapidly in the remaining years of the decade. The Department of Defense can provide a testbed to reengineer the health care system to provide greater access to care, improved productivity, increased efficiency, equity, convenience, and reduced costs.

The reengineering process begins by inserting information/communication technology into the military health care system. The latest initiative in support of that goal is called "Telemedicine." General Gordon R. Sullivan, Chief of Staff of the Army, stated in a recent National Forum on Telemedicine that "We project power by leveraging telemedicine on the battlefield." In this sense, telemedicine reduces risk to Service members and uses technology to maintain the edge over hostile and threat forces.

In September 1994, the Assistant Secretary of Defense, Dr. Stephen C. Joseph, charged the Army Surgeon General, Lieutenant General Alcide LaNoue with responsibility for establishing a plan to develop telemedicine projects to support the National Health Care Reform goals and objectives. The vision and over-arching goals of the testbed organization are shown in Figure 1-1.

Telemedicine Principles



Over-arching Goals:

- *Readiness Orientation*
- *Patient Focus*
- *Rapid Prototyping*
- *Outcome-based Metrics*
- *Open Systems Architecture*
- *Sound Business Practices*

Telemedicine projects world class health care to patients and providers anytime, anywhere.

Figure 1-1. Telemedicine Vision and Over-arching Goals

The Medical Digital Imaging Support system is a project under the telemedicine umbrella that digitizes patient images and sends them via fiber optic cable to a storage unit. The computer network links different types of imaging equipment or modalities within a facility including: computed radiography, computed topography, digital angiography, nuclear medicine, ultrasound, magnetic resonance and digital spot imaging (Smith, 1994). Images are stored in a work storage unit and archived images are further stored within an optical disk jukebox (See Figure 1-2). There are three levels of data storage: the short term which stores images in the system's random access memory, intermediate storage which stores the images on magnetic media, and long term storage which stores images on optical disc. The system allows the physician to access stored images from the worksite. With film-based imaging technology, physicians would have to retrieve images from a storage area often in a remote part of the hospital. The system also has a wider range of exposure times, which makes the system more forgiving in producing

readable images for the inexperienced technician. The implication is that less images are necessary and the system may reduce image retakes necessary with film-based technology.

In the future, after networks are installed within a facility, they can be linked to other satellite facilities using "teleradiology." The teleradiology capability allows the medical treatment facility (MTF) to communicate with other MTFs in a network via fiber optic cable or satellite (Cade, 1993).

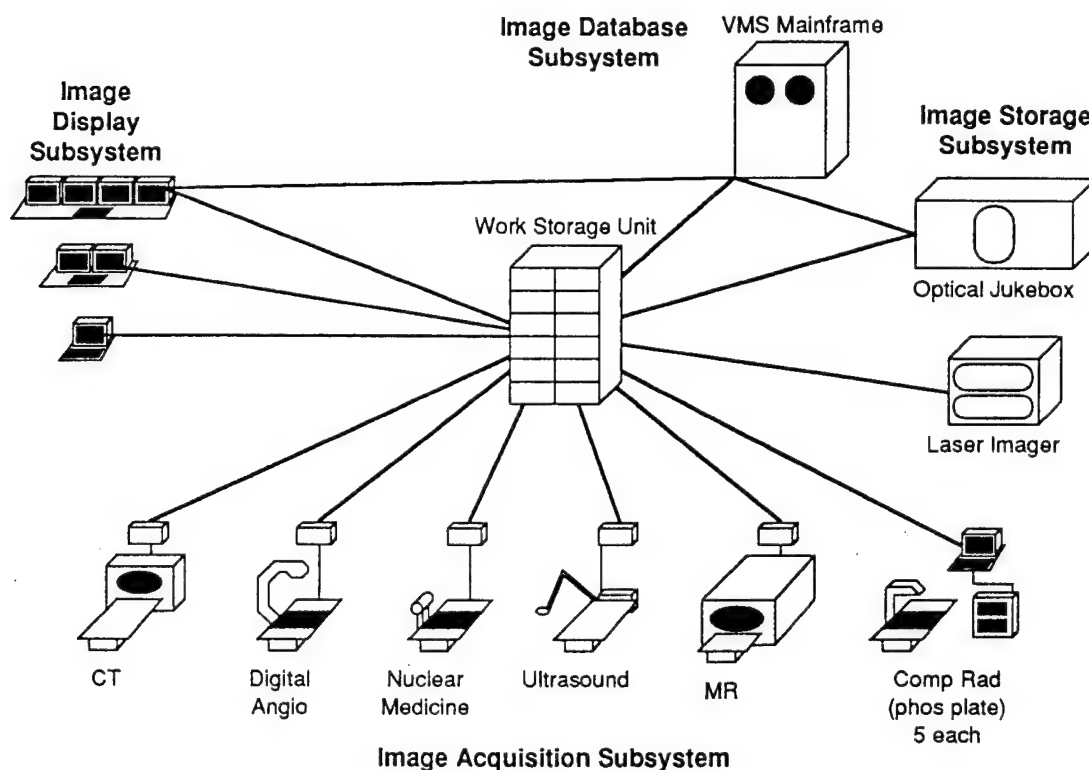


Figure 1-2. The MDIS System Configuration

The first Department of Defense (DoD) facility to receive the MDIS system was Madigan Army Medical Center (MAMC). Madigan is installing the 3rd phase of a 3 phase MDIS implementation schedule. As with most new technology systems, there is a learning curve associated with using the system and the first operational users experience growing pains as they learn to use the system effectively. Several modifications to the software interfaces between hospital information systems and between modalities has slowed the full implementation of the MDIS system at Madigan.

The MDIS Project Manager has a vision to modernize hospital imaging systems to meet the current and future needs of DoD medical treatment facilities. In support of this vision, Lieutenant General Frank F. Ledford, the previous Army Surgeon General said, "I am totally committed to making imaging a reality for military medicine in partnership with our sister services. We have a chance to design the future and I intend to grasp it" (Cade, 1993). Georgetown University and University of Washington conducted a Digital Imaging Network System (DINS) evaluation project which provided a benchmark in picture archiving and communications technology. There were four major conclusions of the project as follows:

- Commercially available digital technology, used under appropriate management and with continuous vendor support, can perform the tasks necessary to maintain clinical utility.
- It was possible to communicate, archive, and display images of diagnostic quality on a computer monitor.
- The technology could improve physician efficiency and availability to treat more patients.
- The technology was accepted by a diverse group of referring physicians and radiologists. The group included neuroradiology, gastrointestinal, nuclear medicine, the intensive care nursery, and radiation medicine.(Crowe, 1991)

Soon after the evaluation project was completed, in September 1991, the Government awarded Loral a \$209 million indefinite requirements contract to develop, test, and field MDIS to DoD medical treatment facilities (Cade, 1993). To date, the Project Office has issued 11 delivery orders for Army and Air Force medical treatment facilities against the contract which expires in September 1995.

Seahawk is a teleradiology project in the Northwest region that will link several medical facilities in a joint Service imaging network called the U.S. West Lion Fiber Ring. The network consists of Army, Air Force, Navy, and Veterans Administration medical treatment facilities and the University of Washington (See Figure 1-3).

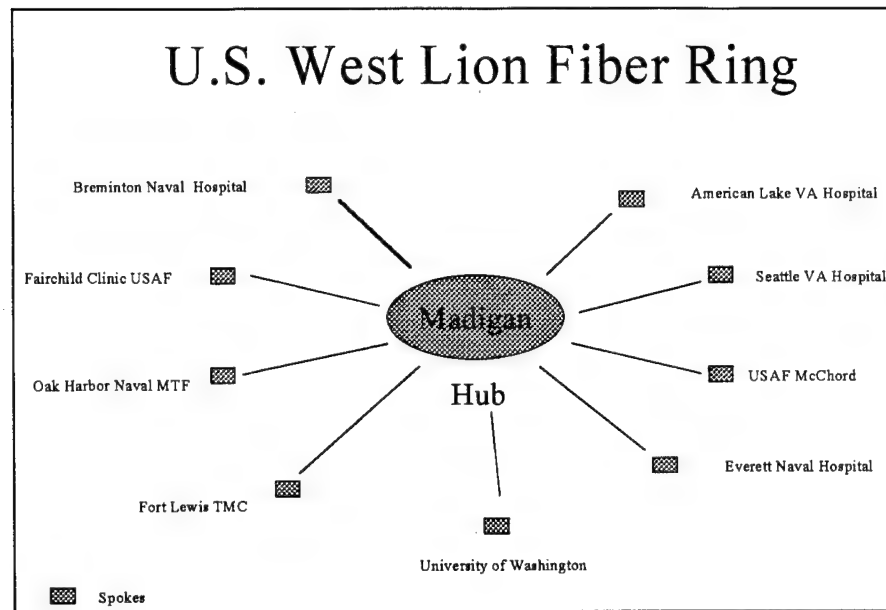


Figure 1-3. Project Seahawk Network Configuration

The project received a \$10 million appropriation in 1994 and the equipment and installation is expected to cost \$6.5 million. The project is designed to increase efficiency through live consultations via videoteleconferencing and decrease patient referrals to other facilities. Cost savings may result by having radiologists consult via telemedicine, eliminating contracted radiologists. The project is also expected to improve the quality of patient care by providing faster patient services.

B. PURPOSE

The purpose of this research is to conduct a cost effectiveness analysis comparing the two types of imaging technologies used by two major Army Medical Centers. Much of this research will build on previous studies, which captured the costs and benefits of digital imaging technology. Ideas for the research project came from the "Futures" section of a preliminary payback study conducted by a Government contractor. The Futures section presents ideas about potential cost savings from the system. These savings need to be measured, validated, and documented.

The three areas covered in detail in this thesis include the amount of images that require retakes, number of lost images, and time it takes for a physician to retrieve an

image taken during previous patient visits. Cost effectiveness is measured by the technology's effectiveness relative to the dollars invested.

C. RESEARCH QUESTIONS

The primary research question is: "Are there cost effectiveness differences between the state-of-the-art digital imaging system and the traditional film-based imaging technology used most frequently by Government and civilian medical treatment facilities?"

This research will address the following subsidiary research questions:

1. Does digital imaging reduce the amount of retakes compared to traditional film-based systems?
2. Does digital imaging reduce the number of images lost within a medical treatment facility?
3. Does digital imaging improve physician efficiency by reducing the time to retrieve images?
4. What is the effectiveness per investment dollar for both systems?

D. SCOPE, LIMITATIONS, AND ASSUMPTIONS

The emerging digital technology has the potential of replacing existing film-based technology in civilian as well as military medical treatment facilities. Therefore, it is paramount that military leaders make informed decisions about whether to purchase new technology. Compared to film-based technology, scientists and medical professionals have discovered many applications of digital imaging technology which improve the quality of patient care as well as efficiency. For example, teleradiology allows remote diagnostic consultation and image transfer support not possible under the old system. With improved access to historical patient images, teaching files can also be constructed to train radiologists and clinicians to detect disease and illnesses through imaging technology.

This research focuses on the clinician, who is the primary user of the MDIS system. The specific areas addressed include image retake rates, frequency of lost images, and time to retrieve archival images. Collected data are analyzed both quantitatively and qualitatively using questionnaires and interviews. Since project Seahawk is still in the

design phase, the cost effectiveness measure used for this project is relatively limited. The MDIS system is functional within Madigan, thus only operations used currently are included in this project. The teleradiology applications are excluded from this study.

A major limitation of this study is that data are only collected at two sites. Since Madigan is the first facility to receive the MDIS system, and has the most experience with digital imaging, it will be the site for MDIS data collection. The representative major film-based medical facility is Fitzsimons. The digital imaging implementation is not yet complete at Madigan. Therefore, the results of this research only represent a portion of the total impact digital imaging technology has on a facility.

The primary assumption made in this project is that the two sites chosen have similar missions, supported populations, radiology protocols, and technical expertise. Another assumption is that physician questionnaires at each site do in fact measure how the imaging technology is perceived by the system's primary user.

E. METHODOLOGY OVERVIEW

The first step in obtaining information for this paper is a literature search on the MDIS system, cost effectiveness analysis techniques, and technical papers about MDIS and other Picture Archiving and Communications (PACS) systems. The next step is to collect data at two comparable major medical treatment facilities. Madigan and Fitzsimons are both Army regional medical facilities, teaching hospitals for military physicians, and support a mixed population of active duty military, dependents, and retirees. Data were collected using two techniques: questionnaires, and interviews with the hospital staff. Personal interviews were conducted with key staff at Madigan and Fitzsimons. The information collected in the interviews supplements and verifies the questionnaire data to validate the results. Several administrative areas of each facility provided cost and workload data. The administrative areas from which data were collected include: resource management, patient administration, logistics, radiology, and legal staff.

F. ORGANIZATION OF THE STUDY

This thesis is divided into five chapters, beginning with the introduction as the first chapter. Chapter II provides background information on previous economic studies on the MDIS system. Chapter III discusses the methodology used to gather and analyze the data. Chapter IV is a detailed analysis of the data. Answers to each of the subsidiary research questions are provided within this chapter. Chapter V summarizes the results and provides insight to decision makers about the effectiveness of each system in terms of dollars invested. This chapter also includes recommendations for future studies concerning the cost effectiveness of digital imaging technology. The Appendices include the questionnaire instrument, detailed questionnaire results, and a format for interviews.

II. BACKGROUND

The world of radiographic technology has undergone tremendous evolutionary change within the last century. One radiology technologist with 30 years experience in the field describes this evolution as "glass to glass." Exactly 100 years ago a German physicist named Wilhelm Konrad Roentgen discovered the X-ray for use in diagnostic imaging. In the early days, diagnostic images were captured on photographic glass plates covered with a thick emulsion. After an image was taken, the emulsion was scraped off and the glass plates were used again. Today these images are captured using digital processes that capture images behind the glass of a computer monitor, hence the "glass to glass" evolution. (Chase, 1994)

This chapter consists of a review of similar studies that have been performed in the past and compares how this research project differs from previous studies. This chapter sets up the follow-on chapters that compare the cost effectiveness of a film-based system to a digital system.

A. PRELIMINARY PAYBACK ANALYSIS

In a preliminary payback analysis, the Project Office contracted with Sherikon to verify prior predictions of potential cost benefits from MDIS, based on micro-analyses conducted by independent researchers. In the Sherikon study, the costs were broken down into first-order effects, second-order effects, and third-order effects based on a Scientific American article by Malone and Rockart (1991). The article describes some of the universal benefits seen by organizations which have installed computer networking information technology systems into the work place to reduce costs, improve productivity, and create innovative ways of doing business. First-order effects are direct costs that are avoided as a result of the information technology system. These costs may include material and labor. The article describes the first-order effect as, "reducing coordination costs by the substitution of information technology for human coordination." The second-order effects describe more intangible benefits such as productivity improvements. Finally, third-order effects represent the long term benefits of the system. An example of a third-

order effect is innovations that improve products or processes that would not be possible without the new information system.

The analysis calculated a system payback period of 5.1 years after total implementation. The net present value for the system was \$9.8 million and a benefit to cost ratio was 2.19 (Sherikon, 1994). Unfortunately, there are some serious flaws with the results. The cost figures for film savings are based on a totally filmless system. However, Madigan runs a dual system at the present time, generating both film copies and soft-copy images so there are no savings on film. Many of the results reported are inaccurate because of this assumption.

In Sherikon's payback analysis, the project office hoped to verify prior predictions by independent researchers based on data from the Digital Imaging Network System project. As more sites receive the MDIS system, more accurate cost and benefit analyses can be conducted to reflect the changing costs and benefits associated with MDIS systems in DoD medical treatment facilities. In large developmental projects such as MDIS, the cost and benefit data evolve as the technology matures. The data collected during this research will be used to validate other cost benefit studies. It represents a snap shot in time of the evolving digital imaging technology.

This research project grew out of the Futures section of the Sherikon study. The following is the list of future research areas in the Sherikon study:

- Reading Times
- Interpretation Times
- *Retake Rates*
- Turnaround Times
- Physician Acceptance
- *Image/Report Availability*
- Teleradiology
- Telemedicine
- Silver Recovery
- Handling and Storage Costs

- Paper Processing
- *Lost Images and Reports*
- Water-soluble Contrast Media.

The italicized bullets were chosen for this project because they are independent of the duality (film and digital images) that exists within the Radiology Department at Madigan.

B. ECONOMIC ANALYSIS FOR MDIS AT THE NEW BROOKE ARMY MEDICAL CENTER

An economic analysis was performed by project office personnel to determine the best course of action for the new hospital at Brooke Army Medical Center, in San Antonio, Texas. The study considered three configurations for the Radiology Department in the new hospital facility. They are as follows:

- Alternative 1: Incorporates the existing MDIS equipment into the new facility (a 20% filmless facility),
- Alternative 2: Move existing equipment to the new hospital and add enhanced equipment (an 80% filmless facility),
- Alternative 3: Use a conventional film-based Radiology Department.

To select the best alternative, the study analyzed incremental costs, that is the cost differences associated with each alternative. The study provides exhaustive cost information on film costs, chemical costs, storage costs, and associated equipment.

The study also reports on the successful implementation of digital imaging technology to date. A radiologist at Brooke indicates that digital imaging has improved the image loss rate from 20% to less than 1% and decreased the image retake rate from a range of 8-12% to less than 5%. The time to retrieve an image from the MDIS system at a workstation is 2 to 3 minutes for images archived on optical storage media. (Winters, 1994) The installation at Brooke is successful in incorporating several modalities, including: computed radiography, computed tomography, ultrasound, and angiography.

This research hoped to obtain similar results when comparing Madigan with Fitzsimons Army Medical Centers.

The Brooke Army Medical Center analysis found that alternative 1 provided a \$113,325 cost savings using a 20% filmless operation. Alternative B cost \$4 million for enhanced equipment but saves \$481,630 by using an 85% filmless operation. A film-based system, Alternative C, cost \$.48 million for reprinting digital images but saved \$3.8 million in maintenance, utilities, and personnel. However, Alternative C incurred additional costs to redesign and reconstruct a Radiology Department in the new facility that could process and store film.

One of the more significant cost benefits of digital imaging discussed in the study involved avoided legal costs. The research indicated that, "in the last two years, the San Antonio Assistant U.S. Attorney estimates that a total of \$1.5 million was paid out in settlement or judgment for three Brooke medical malpractice cases resulting from a lost diagnostic image." (Winters, 1994). Consideration was given to other legal claims involving lost images at Brooke and the conclusion drawn was that malpractice settlements cost the Government approximately \$1 million per year. Combining the costs with the benefits favors Alternative 2, moving the current MDIS equipment from the old facility and adding enhancements to obtain an 85% filmless Radiology Department.

C. EVALUATION OF MDIS BASED ON CLINICAL EXPERIENCE

The first Department of Defense facility to receive the MDIS system was Madigan Army Medical Center in March 1992. Madigan is installing the second phase of a three phase MDIS implementation schedule. The two articles discussed previously represent empirical research in the area of cost benefit and cost effectiveness. The remaining articles discussed in this Chapter report on the performance of the system under operational conditions.

An article written by one of the system's early radiology users reports both good and bad lessons learned by the first operational users. On the good side, the system has archived more than 375,000 computed radiography (CR) images within the system's

operational life. The MDIS system has improved the medical treatment facility's ability to store and retrieve images. (Smith, 1994) Previous studies indicated that on the average a large treatment facility such as Madigan lost up to 38% of the images taken (Leckie, 1992).

In addition, fail-safe strategies have been continually improved to maintain continuous clinical image availability during times when the MDIS system or components malfunction. After two years of using digital imaging, Madigan reports a 1% image loss rate, primarily due to computed radiography interface errors or human errors. Similarly, ergonomic aspects of the equipment placement were refined with time which improved system useability. Furthermore, unique patient cases can be assimilated into teaching files, improving the physician training program. Finally, the MDIS system can correct an over or under exposed image through electronic window and leveling techniques (adjustment of the brightness and contrast on the computer monitor), providing for a diagnosis without retaking the image. (Smith, 1994)

On the downside, the system has not been successful in networking several of the other imaging modalities, including magnetic resonance, nuclear medicine, ultrasound, angiography, and the cardiac catheterization lab due to software interface problems. (Smith, 1994) Another operational problem with the system involves the radiologists' need for hardcopy film. Throughput is the process whereby the system preloads images for the radiologists' diagnosis. At Madigan, the system cannot provide adequate throughput of images to keep the radiologists busy enough to meet the demands of the workload within the department. However, Brooke Army Medical Center also installed the MDIS system and the Radiology Department has almost completely converted to softcopy diagnosis. Their Radiology Department has obtained a 20% filmless operation and hopes to obtain an 85% filmless operation with additional MDIS equipment (Winters, 1994).

III. METHODOLOGY

A. DEFINING THE PROBLEM

The purpose of this research is to analyze three measures of effectiveness (MOEs) for the MDIS system. The three MOEs or measurement criteria are retakes, physician waiting time for archival image retrieval, and number of images lost within a facility. This analysis compares measurable information that is available from Madigan Army Medical Center for digital imaging technology with a conventional radiology system at Fitzsimons Army Medical Center. Many other criteria can be measured in the future as the system's phased installation is completed.

B. PROJECT SCENARIO

The MDIS system is an information management system which primarily supports the physician in diagnosing and treating diseases which require medical imaging modalities. The system digitizes the images and stores them on optical discs for future use, eventually eliminating the need for hardcopy film and record storage areas. The modalities currently available at Madigan include computed radiography, fluoroscopy, and digital spot imaging. The indefinite requirements contract calls for integrating other modalities as well, including: magnetic resonance imaging, computed tomography, ultrasound, and nuclear medicine. Software problems have slowed the implementation process and to date it is unknown when the other modalities will be integrated within the system. Hence, this research effort only considers a portion of the true cost information (retakes, archival images, lost images).

The digital imaging facility used in this research project is Madigan Army Medical Center located in Tacoma, Washington. Madigan opened a new hospital at Fort Lewis in February 1992. The original hospital, built in 1944, was a sprawling, one story cantonment style building designed to prevent the spread of disease and fires. Today the hospital supports 99,000 active duty members, their dependents, and military retirees. The new facility is equipped with many innovative technologies including: energy efficient

skylights, a medical mall (with "one stop shopping for your health care"), a robotic medical material transport system, and the medical digital imaging and support (MDIS) system. The hospital's average daily workload consists of approximately 40 surgeries, 29,500 laboratory procedures, 3,700 prescriptions filled, 2,600 images taken, and 7 babies delivered. The staff consists of 1400 civilians, 700 officers (400 physicians), and 800 enlisted. (Public Affairs Office, 1995)

C. BASELINE SCENARIO

The baseline facility used in this research is Fitzsimons Army Medical Center located in Aurora Colorado. The medical treatment facility has multiple missions: maintain or restore health, train health care providers, provide quality health care, and obtain excellence through research. The hospital serves 57,960 patients within a 40 mile catchment area. The hospital provides tertiary care and consultant responsibilities in a 14-state region. There are 155 military physicians, 22 civilian physicians, and 121 continuing medical education physicians. The facility averages 47,000 outpatient visits per month. (Public Affairs Office, 1994)

The radiology department primarily uses conventional radiology imaging equipment (film-based technology). They also have a mini-PACs system which enables the radiologist to store and retrieve images using a computer system. The Chief, Radiology plans to have personal computers modified and networked with the mini-pacs so that physicians will be able to view the images at their worksites.

D. JOINT TACTICAL COMMUNICATIONS (TRI-TAC) METHODOLOGY

The Joint Tactical Communications (TRI-TAC) Office, located at Fort Monmouth, New Jersey, is responsible for the Cost Effectiveness Program which includes system planning, trade-offs, testing, economic analyses, and cost analyses involved in the acquisition processes of joint tactical communications systems and equipment. They use a Cost Effectiveness Program Plan (CEPP) which outlines measures of effectiveness, life cycle cost estimating, technology forecasts, communications scenarios, risk analyses, and simulation.

The CEPP is a three volume document. The first volume provides an overview of the scope of the plan, Service and agency relationships, and establishes the responsibilities for a joint Service/Agency Cost Effectiveness Coordinating Committee. The second volume contains a conceptual model used for this cost effectiveness research project. It also provides guidelines for the modification and application of the model to a myriad of new technology equipment alternatives. The third volume provides instructions and guidance for the computation of life cycle cost estimates. It also provides formats for reporting in compliance with Department of Defense financial regulations and policies.

The Department of Defense often uses the TRI-TAC methodology as a decision making tool in evaluating systems. The method yields a number that tells the cost effectiveness per dollar of investment cost for multiple MOE assessments. The TRI-TAC methodology also uses figures of merit, subjective weighting criteria, an effectiveness index, and utility theory.

System effectiveness can be expressed as one or more figures of merit representing the extent to which the system is able to perform the intended function. The figures of merit (FOM) chosen for this research project are availability, dependability, capability, and useability. Availability refers to the degree the system is operable when required by the user to perform a specific mission task or procedure. Availability is a function of operating time (reliability) and downtime (maintainability and supportability). Dependability is the measure of the system operating condition at one or more points when needed. Capability and useability are both figures of merits which describe the system's performance parameters. Examples of capability include storage capacity, image clarity, and band of acceptable image quality. Useability refers to the ease with which the mission can be accomplished with each alternative. Useability interfaces with the human factor or system operator.

As mentioned previously, the three MOEs measured in this research effort include retakes, time to retrieve historical images, and lost images. The quality of the image technology alternative is a function of each MOE. The function identifying this relationship is shown:

$$Q = f(R, H, L)$$

where,

R = Retakes

H = Historical Images

L = Lost Images.

Each MOE is given a utility value using Table 3-1. The utility figure reflects the relative performance of an alternative with respect to the baseline alternative. Therefore, Fitzsimons automatically gets a baseline score for each MOE. A qualitative assessment of the digital system performance is made for each MOE based on the utility assignment criteria. The utility for the alternative, Madigan, is discussed in greater detail in the analysis chapter.

<i>UTILITY</i>	<i>CRITERIA</i>
0-2	Barely meets minimum essential requirements
2-4	Less effective than the baseline
5	Baseline
6-8	More effective than the baseline
9-10	More effective to the extent that the MOE should be a principal consideration in the selection of a preferred alternative.

Table 3-1. Utility Assignment Criteria

After the utility values are determined for each MOE, weights are assigned to each figure of merit based on its contribution to the system's performance as a whole. The criteria for determining the relative contribution to the system can be subjective. Therefore, a sensitivity analysis maybe necessary. When each FOM is weighted for each MOE, a matrix of values is constructed to establish the total FOM for each alternative. These values are scored subjectively to determine the overall effectiveness value.

The overall effectiveness score for each alternative is divided by the equipment and maintenance costs for each system. The operations costs are not included in this project because Madigan, the digital site, is still running a dual system which incorporates many practices of the film-based technology system. A net present value calculation for each

alternative serves as the denominator when deriving the final units of effectiveness per dollar investment for each alternative.

Every few years the Office of Management and Budget (OMB) publishes a directive concerning discount rates to be used in Government cost analyses. For the purposes of this study, dollar values are given in nominal terms. Discounted dollars help determine the value of future benefits and costs associated with different alternatives. The most current OMB Circular Number A-94 dated February, 1994 mandates using 5.5% for spread sheet calculations when the time horizon for the net present value calculation is seven years.

E. CONSTRAINTS ON THE PROJECT

Budgetary: The travel cost to collect data for this research is limited to one trip to each facility to establish points of contacts, collect information, and take measurements. The total cost of this travel is approximately \$1800.

Data Collection Sites: Because the MDIS system is new there are only two operational sites from which to collect information: Brooke Army Medical Center, and Madigan Army Medical Center. Madigan was selected for this study because it has had the system the longest of the two facilities.

F. DATA COLLECTION

Data was collected primarily via questionnaires and interviews with hospital personnel at the two Army Medical Centers. Questionnaires and interviews were chosen as the collection instruments because the respondents are the subject matter experts regarding imaging technology. Therefore, this research focuses on the primary users of the MDIS system, the physician. The research assumes that the two medical treatment facilities have similar workload data.

The dendritic analysis technique is used to decompose each measure of effectiveness into their critical components. The dendritic analysis approach (Test and Evaluation Guide, 1993) is used to chart the primary, subsidiary, and tertiary research questions and the test measurement technique used to answer the questions (Figure 3-1).

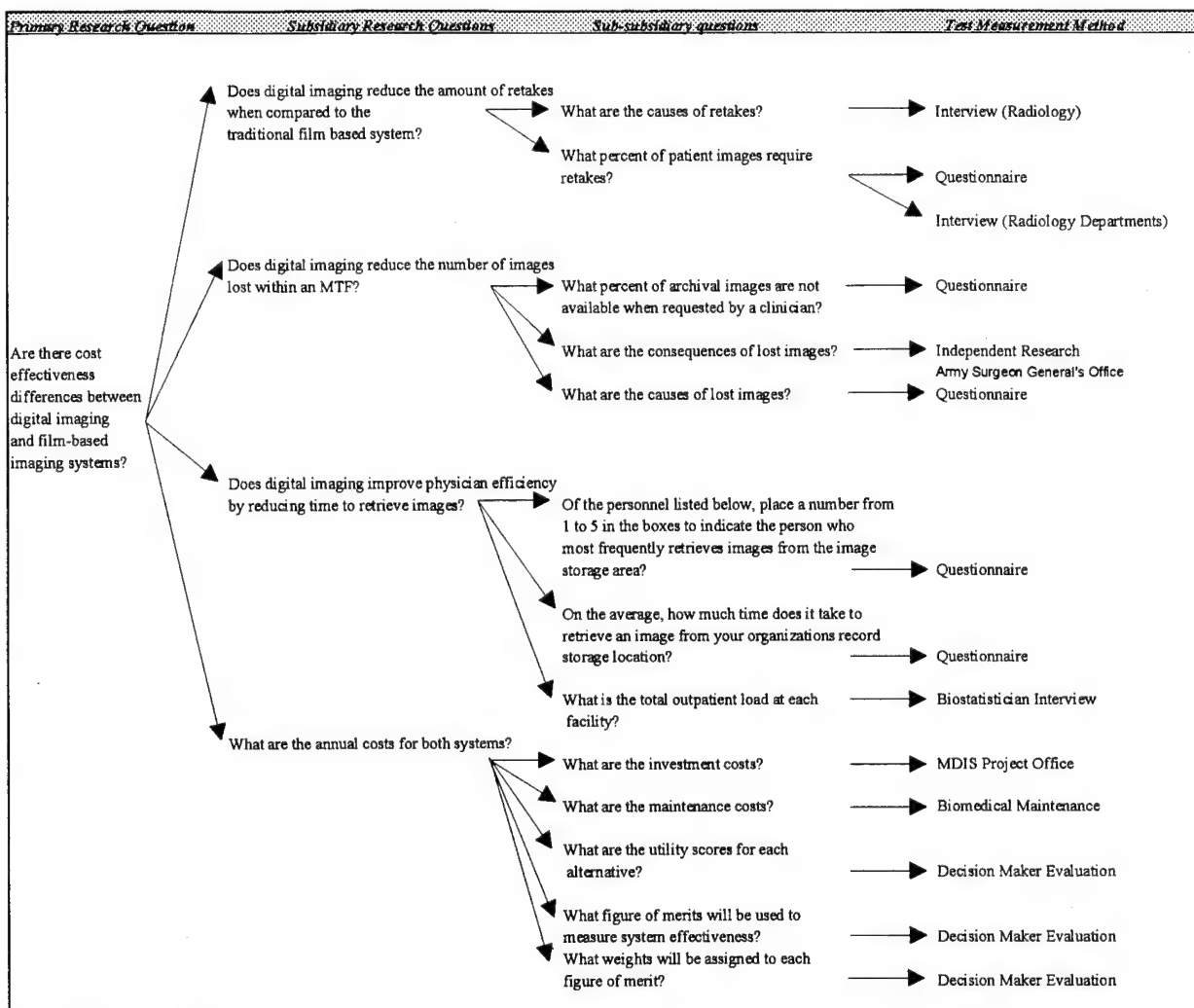


Figure 3-1. Dendritic Approach to Cost Effectiveness Analysis

G. QUESTIONNAIRE

The questionnaire was validated through a pilot test. The questionnaire was used to answer the questions in the Dendritic Approach (Figure 3-1). The questionnaire was first administered to clinicians in Army Medical Centers other than Madigan and Fitzsimons. The pilot test validated the numbers and thresholds in the survey's multiple choice questions. Three Army Medical Centers participated in the pilot test including Brooke, Tripler, and Eisenhower and the clinical respondents provided little constructive criticism.

The questionnaire was administered to physicians who use the Radiology Department at each site. Physician opinions concerning their experience with the imaging technology present at their facility was sought. The desired sample size was a minimum of 30 respondents at each medical facility. The Central Limit Theorem provides a rule of thumb stating when the sample size (n) is ≥ 30 ; the sample has approximately a normal distribution. In an analysis of variance test, one of the assumptions made is that the population or treatment distributions are all normal with the same variance. By obtaining a sample size greater than 30, normality can be assumed by the Central Limit Theorem. (Devore, 1991)

The technique used to select respondents to the questionnaire is a judgmental sample. Questionnaires were given to physicians who volunteered their time (see Appendix A, sample questionnaire). The questionnaire was administered to physicians who worked with the Department of Radiology at the two medical treatment facilities in October, 1994. Approximately 100 questionnaires were distributed at each site. At Madigan, the response rate was 58 responses out of a pool of 400 (14.5 %). At Fitzsimons, the response rate was 36 responses out of 295 (12.2%). The analysis assumes that the opinions of the respondents are representative of the population at each site. The consolidated questionnaire data collected are shown in Appendix B.

H. INTERVIEWS

Interviews with hospital personnel were conducted at the work site after completing the questionnaires. The interviews collected specific information for the research project that was not available from the questionnaire responses. The information validated and extended the information in the questionnaires. Interviews were primarily conducted with hospital support staff and remained anonymous if requested; otherwise the information used in the study is quoted from the source. Follow-on telephone interviews were conducted as needed using the statement in Appendix C.

IV. ANALYSIS

The analytical portion of this research demonstrates both quantitatively and qualitatively whether or not the MDIS system is cost effective for the Army based on data collected on three measures of effectiveness (MOEs). The three MOEs are: retakes, physician waiting time for archival image retrieval; and number of images lost within a facility. A comparison between two similar medical treatment facilities focusing on physician opinions will be the basis for this analysis. First, the three MOEs will be analyzed to identify the trends and the associated costs for each. Questionnaire data are used in the following paragraphs to answer the subsidiary research questions. Factual interview data are used in spreadsheet computations. Next, a modified life cycle cost will be computed for each alternative using maintenance and capital investment costs only. Finally, units of effectiveness per dollar investment will be determined for each alternative using the TRI-TAC Methodology discussed in Chapter III.

A. DOES DIGITAL IMAGING REDUCE THE AMOUNT OF RETAKES WHEN COMPARED TO THE TRADITIONAL FILM-BASED SYSTEM?

Image retakes occur for a variety of reasons. The major categories for image retakes within the Radiology Department at Fitzsimons include over or under exposure, fog film, poor patient positioning, processing error, artifacts on film, machine error, and technician error (see Appendix B). At Fitzsimons, poor patient positioning causes about 50% of the retakes. The second largest category of retakes is over and under exposure of the radiographic plates. This accounts for 25% of retakes at Fitzsimons (Leonard, 1994). Each of these causes can be improved with the implementation of digital imaging technology. Under and over exposed film can be accommodated with window and leveling techniques and a diagnosis can be obtained. As clinicians become more proficient with this technology, poor patient positioning can be overcome by manipulating the digital image. Both poor positioning and under/over exposure of film should result in a significant difference between digital imaging and film-based imaging technologies.

Retake rates at Madigan are captured in a much less rigid manner because some sections are filmless and use only softcopy images while the majority of sections still produce hard copy film. Softcopy retake data are not captured and are not reflected in the figures provided by the Madigan Radiology staff. (Carter, 1994) With the digital imaging technology, films can be processed over a wider range of exposure times. This results in a more forgiving system than conventional radiology in terms of over and under exposed films. With conventional radiography, a natural feedback mechanism exists in which an underexposed film is too light whereas an overexposed film is too dark. (Smith, 1994)

Retake data were collected at the two medical treatment facilities to determine whether the digital imaging technology significantly changed the number of retakes. Both facilities were able to provide 10 months of retake figures expressed in percentage of images taken in the calendar year, 1993. The graph shown below (Figure 4-1) depicts the month by month comparison between the two MTFs. The zeros depict months in which the data were not available. Madigan did not have figures for October and November due to system downtime and Fitzsimons did not have the retake figures for January and February.

An interesting trend appeared in the data provided by Madigan. The digital system became operational in the early part of 1992 and retake figures were captured for the last 6 months in 1992 with a mean retake rate of 7.9%. In 1993, the retake rate began at 5.9% and steadily declined to 2%. This suggests a learning curve which over time will show significant differences between digital imaging technology and conventional imaging technology.

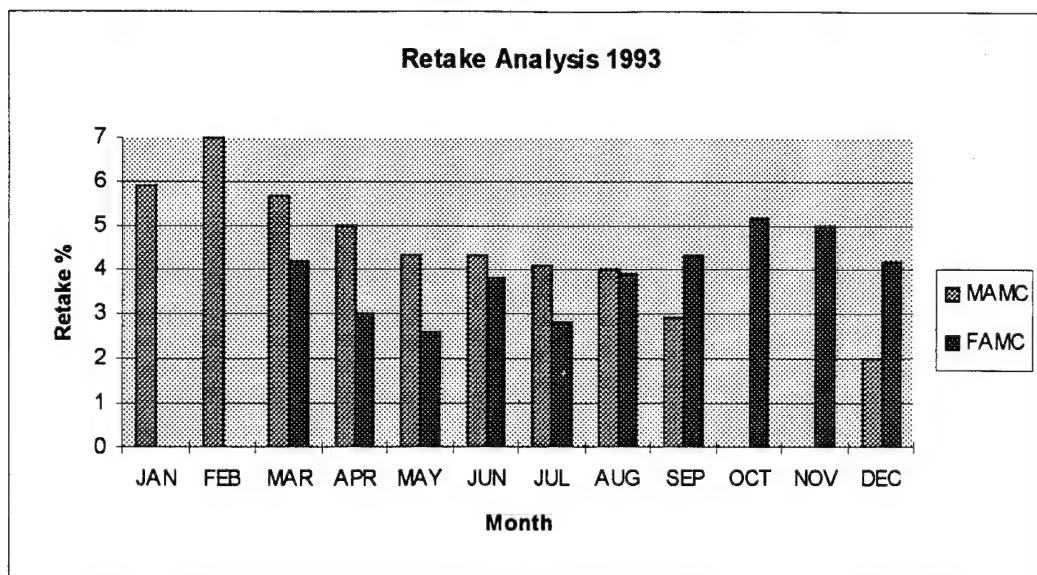


Figure 4-1. Retake Analysis for Madigan and Fitzsimons 1993

A one-way analysis of variance (ANOVA) with a 95% confidence interval was conducted to determine if the retake rates at the two different facilities were statistically different. The null hypothesis states that there is no difference between the Madigan retake rate and the Fitzsimons retake rate as a result of the different imaging technologies. The p value is much greater than the .05 value necessary to reject the null hypothesis. Therefore, based on the retake rates provided for 1993, there is no significant difference in the amount of retakes generated by the different imaging technologies (see Figure 4-2). This finding is further substantiated by a questionnaire administered to the physician staff at both facilities. The majority, 65% of the MAMC staff and 61% of the FAMC staff felt that the retake rate was between 1-10% (see Appendix B).

Anova: Single Factor						
SUMMARY						
<i>Groups</i>	<i>Count</i>	<i>Sum</i>	<i>Average</i>	<i>Variance</i>		
MAMC	10	45.2	4.52	2.132889		
FAMC	10	39	3.9	0.773333		
ANOVA						
<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Between Groups	1.922	1	1.922	1.322679	0.265163	4.413863
Within Groups	26.156	18	1.453111			
Total	28.078	19				

Figure 4-2. ANOVA Comparing Madigan and Fitzsimon Retake Rates 1993

The data that were collected are not inconsistent with the information stated, if consideration is given to the possibility of learning to use the system to its full capability, particularly in terms of under/over exposure and poor patient positioning. Figure 4-1 only considers a strict average of all monthly retake data. If one considers the learning process then the early months skew the true average and the true average is more realistically lower when one averages the last six months of data collected in 1993. Validation of this theory could best be accomplished by collecting the retake rates at both facilities for 1994. However, this information was not available for this project.

In summary, the results of the questionnaire do not show a significant difference between MDIS and film-based technology with regard to retake figures based on a simple average. The data clearly show a trend of decreasing retake rates at Madigan, possibly due to the learning associated with window and leveling techniques and making a diagnosis from an image that was not positioned correctly. More data need to be collected to validate this hypothesis.

B. DOES DIGITAL IMAGING REDUCE THE NUMBER OF IMAGES LOST WITHIN AN MTF?

Under a conventional radiology system, there are many reasons that records are lost. For example, both Madigan and Fitzsimons are Department of the Army teaching

institutions in which many resident physicians are assigned. Consequently, images are frequently retained by physicians to provide future teaching files. Many patients do not trust the filing system and check-out images without returning them to the medical treatment facility. The frequency of lost images is also a function of the size, capacity, and population supported by a facility. Often records end up in clinics, physician offices, ward administrative areas, or within "black holes." The final major cause of lost images is administrative type errors such as mixing up record jackets, misfiling images, or recording incorrect patient data on an image.

A study conducted in 1992 by Dr. Bob Leckie, radiologist, indicated that before the MDIS system was installed at Madigan up to 38% of patient images were unavailable for the physician when requested. Follow-on studies at other major medical centers (Tripler, and Brooke) revealed similar loss rates (Leckie, 1992). The results of the questionnaire responses from physicians at Fitzsimons support Leckie's data. The majority of physicians felt that images were unavailable to them between 5-20% of the times requested. With the digital imaging system, the majority of the physicians (29%) at Madigan felt that archived images were unavailable due to loss less than 5% of the times requested. On the other hand, many physicians at Fitzsimons (33%) felt that images were unavailable due to loss 5-10% of the times requested. (Appendix B)

Although difficult to assess a cost saving, the most severe consequence of a lost image is delayed diagnosis and treatment, which can result in death. Some other unfortunate consequences include inappropriate treatment, poor quality patient care, and increased radiation exposure to patients where images are retaken. Legal claims for military dependents and retirees may result from any of the above consequences. The magnitude of the legal costs associated with those claims was demonstrated at Brooke Army Medical Center in the Winters Economic Analysis discussed in Chapter II (Winters, 1994).

The results of the questionnaire validate previous studies indicating that digital imaging technology decreases the number of images lost within a facility. The majority of physicians at Madigan felt that images were unavailable less than 5% of the times

requested, a significant improvement over Leckie's findings (38% loss rate). Specific benefits are difficult to determine due to the qualitative nature of the consequences of lost images.

C. DOES DIGITAL IMAGING IMPROVE PHYSICIAN EFFICIENCY BY REDUCING TIME TO RETRIEVE IMAGES?

A physician's time is very valuable. Finding ways to improve physician efficiency will generate qualitative as well as quantitative savings in military medical treatment facilities. The frequency of response to question 2, "On the average how much time does it take to retrieve an image from your storage location?" shows a significant difference between facilities. The largest percentage of physicians at Madigan (47%) reported that archival images are available to them within 10 minutes. By comparison, 42% of the physicians at Fitzsimons responded that it takes more than 2 hours to retrieve an image from the Radiology records storage area. (Appendix B)

An analysis of the clinic outpatient visits at Madigan shows an additional 26,000 outpatient visits between 1991, when Madigan used conventional film technology, and 1993, when Madigan used digital technology (see Figure 4-3). It is unclear what caused this additional outpatient workload. The number of assigned physicians has not increased but the in-house staff is treating more patients on an outpatient basis. The improved physician efficiency may be due in part to the ability to retrieve archived images faster. Conversely, outpatient visits at Fitzsimons have decreased dramatically over the same time period. The cause of this decrease is also unclear, but it could be related to the decreasing patient population at Fitzsimons Army Medical Center due to downsizing at nearby military bases. Recently the hospital was included on the Base Realignment and Closure list. This thesis assumes that using conventional technology has not caused the decrease in outpatient visits at Fitzsimons.

Detailed data were unavailable to draw specific conclusions about physician efficiency as related to the digital imaging system. In the future, the teleradiology

initiative, "Project Seahawk", hopes to demonstrate improved physician efficiency through the use of remote consultations and radiologic diagnoses.

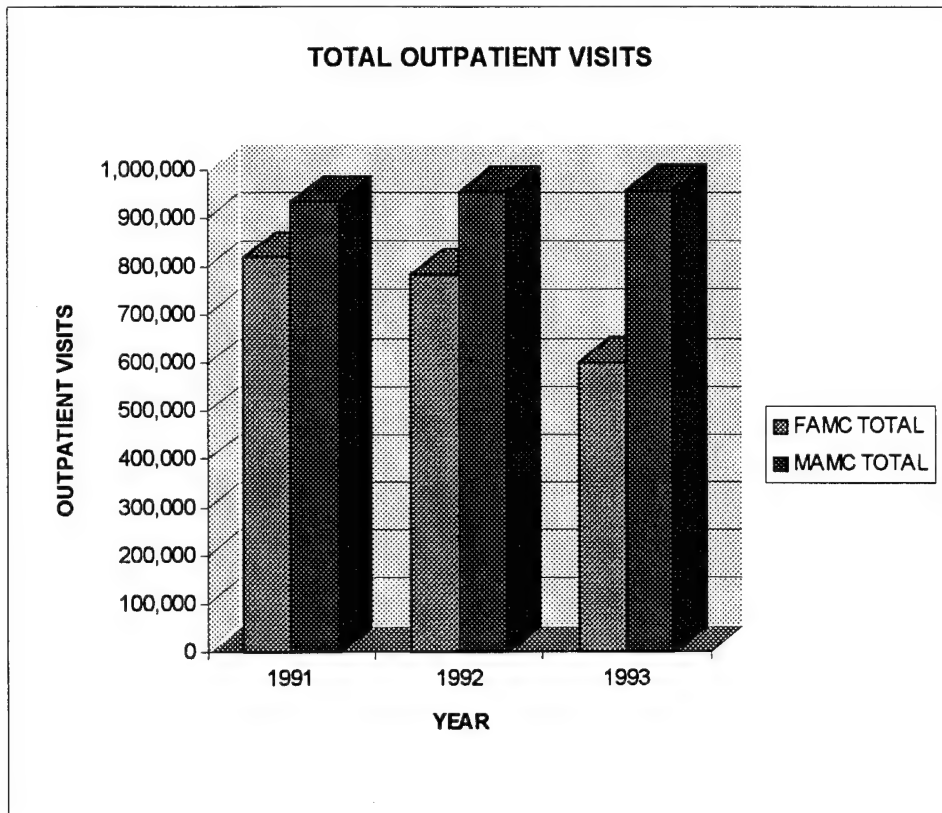


Figure 4-3. Number of Outpatient Visits

The results of the questionnaire clearly show that physicians can retrieve archived images faster under a digital technology imaging system. It remains unclear as to whether this time saving tool improves physician efficiency because data are not available to validate how physicians at Madigan use their time.

D. MODIFIED LIFE-CYCLE COST CALCULATION

To calculate cost effectiveness, one must begin by examining the overall system cost. For the purposes of this research, the system cost only includes the investment equipment cost and maintenance cost. Direct costs such as film, processors, and film processing chemicals are not included in the system cost because Madigan is running a redundant system using both digital imaging and a film back-up. Operations costs are also

not considered due to the uncertainty associated with staffing when Madigan goes to a strictly filmless radiology department. To date, it is unknown whether digital imaging technology will reduce staffing requirements. Therefore operations costs are excluded from the analysis.

The MDIS system is a joint Service acquisition project with the Army Medical Department currently acting as the lead agent. An indefinite requirements contract was selected for this procurement because the project office wanted to assess the commercial product before deciding to place more orders against the contract. With this fixed-price type of contract, the Government can place orders without discussing price, quantity, or performance period with the contractor (Contingency Contracting, 1993). If the Government is not satisfied with the product performance, there is no obligation to place any more delivery orders. In this way, the project office can control how many systems will be fielded to DoD medical treatment facilities.

To date, the project office has issued 11 delivery orders against the indefinite delivery order contract. The contract was signed in September 1991 and was supposed to expire in September 1994; however, the contract was recently extended for one year. Progress payments are made to the contractor based on a milestone concept. There are three phases for the total installation and each phase has four major steps, including receipt of equipment, installation of equipment, system integration, and total integration. Each of these major steps has specific milestones. When a milestone is 80% complete, an 80% payment is made to the contractor. The remaining 20% is paid after each milestone is completed and the Government conducts Acceptance Testing. (Romlein, 1994)

The total investment costs including installation, integration, and acceptance testing by phases at MAMC are shown below:

	<i>MAMC Costs</i>
Phase I	\$5,415,923
Phase II	\$2,092,999
Phase III	\$2,354,556
Total	\$9,863,478

Table 4-1. Total Investment Costs at MAMC (Winters, 1995)

The MDIS contract contains a one year warranty clause from the day of Government acceptance. None of the phases at the MAMC site have been completed. Therefore, the warranty period has not started on any phase of the MAMC implementation process. The maintenance costs begin accruing when the warranty period expires and will be phased in upon completing Government acceptance testing. The maintenance costs negotiated previously are shown below in Table 4-2. Maintenance costs have been separated by phases, spokes (satellite medical treatment facilities), and specific equipment lines (optimized workstations and RIS terminals).

<i>Cost Description</i>	<i>Maintenance Cost</i>
Phase I subsystem	\$ 363,309
Phase II subsystem	\$ 155,463
Phase III subsystem	\$ 110,147
Fairchild	\$ 44,960
McChord	\$ 26,314
RIS Terminals	\$ 4,356
Optimized workstation	\$ 1,629
Total Maintenance Cost	\$ 706,178

Table 4-2. Estimated Annual Maintenance Costs for MAMC MDIS System (Winters, 1995)

The cost of the film-based imaging system at Fitzsimons is based on the property records for each piece of equipment. The Radiology hand receipt is separated into eight separate documents with a corresponding dollar value of \$14,796,653. The system used to account for the equipment does automatic depreciation calculations in accordance with applicable regulations.(O'Bailey, 1995) The current dollar value is not used in the modified life-cycle cost spreadsheet because the \$14 million represents a sunk cost. To maintain the current system, costs for capital investment equipment, also called extended Medical Care Support Equipment (MEDCASE) requirements average \$4.0 million. (Mericie, 1995). The MEDCASE manager provided the 1993 requirements as shown in Table 4-3. The table's figures represents a high end year, with costs close to \$5 million. In the two subsequent years, the MEDCASE funding has dropped significantly because Fitzsimons is a candidate for Base Closure. This thesis does not use information from this

period and assumes that MEDCASE requirements would remain the same if not threatened by base closure.

<i>NOMENCLATURE</i>	<i>PRICE</i>
Computerized Dosimetry System	47,369
Modular Building	97,500
Upgrade Laser Camera (CT)	88,007
Transcranial Doppler System	19,071
X-Ray System Mobile	41,500
Linear Accelerator	1,536,850
X-Ray Apparatus	130,000
Scintillation Camera	501,578
CT	1,300,000
Miscellaneous Support Equipment	1,371,452
File Storage System	125,000
Total	\$5,258,327.00

Table 4-3. Fitzsimons New Equipment Costs for 1993

Maintenance of the Radiology film-based equipment is accomplished by the biomedical repair section. The only complete year of maintenance costs the facility could provide showed an annual cost of \$469,768 (McCune, 1995). The Chief of Biomedical Maintenance, Fitzsimons breaks out the maintenance costs for 1994 as follows:

<i>DESCRIPTION</i>	<i>COST</i>
Man-hour Costs	30,312
Repair Parts	34,246
Contract Costs	405,210
Total	\$469,768

Table 4-4. Fitzsimons Annual Maintenance Costs

The modified life-cycle cost spreadsheets are shown in Table 4-5, for each facility. For the purposes of this study, only the investment costs and maintenance costs are included in the calculations. The discount rate used is 5.5% in real dollars in accordance with Office of Management and Budget Circular Number A-94 (February, 1994).

MAMC Life Cycle Cost (minus Operations)								
Total Investment Expense	9,863,478							
Maintenance Cost	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Discounted \$
Phase I subsystem	363,309	363,309	326,978	326,978	290,647	290,647	290,647	1,846,162
Phase II subsystem	155,463	155,463	139,916	139,916	124,370	124,370	124,370	789,986
Phase III subsystem	110,147	110,147	99,132	99,132	99,132	88,117	88,117	568,140
Fairchild	44,960	44,960	40,873	40,873	36,786	36,786	36,786	230,925
McChord	26,314	26,314	23,922	23,922	21,529	21,529	21,529	135,153
RIS Terminals	4,356	4,356	4,356	4,356	4,356	4,356	4,356	24,755
Optimized workstation	1,629	1,629	1,629	1,629	1,629	1,629	1,629	9,258
Total Maintenance Cost	706,178	706,178	636,806	636,806	578,449	567,434	567,434	3,604,379
FAMC Life Cycle Cost (minus Operations)	Net Present Value MAMC							13,467,857
	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	
New Equipment Cost	4,000,000	3,791,469	3,593,810	3,406,455	3,228,867	3,060,537	2,900,983	2,749,747
								18,665,981
Maintenance								
Man-hours	30,312	28,732	27,234	25,814	24,468	23,193	21,984	20,838
Parts	40,688	38,567	36,556	34,650	32,844	31,132	29,509	27,970
Repair Contracts	405,210	384,085	364,062	345,082	327,092	310,040	293,877	278,556
Total	476,210	451,384	427,852	405,547	384,405	364,365	345,369	327,364
								2,222,232
	Net Present Value FAMC							23,110,445

Table 4-5. Modified Life Cycle Cost

The net present value for Madigan (MAMC) is significantly lower because the digital imaging system is new. The equipment replacement figures reflect that several items will be covered under a warranty for one year within the time horizon of the spreadsheet (Romlein, 1995). The total modified life-cycle cost figure for each system will be used as the denominator in the final cost effectiveness calculation.

E. COST EFFECTIVENESS CALCULATION

The first step in the TRI-TAC methodology for determining cost effectiveness is to specify the utility values for each measure of effectiveness. The baseline figures will simply be 5 for each MOE as shown in Table 3-1. The more difficult task is to assign values to the alternative, the digital imaging system. Retakes showed only a slight difference when comparing actual rates reported in the questionnaire by the radiology department. Hence, the utility assignment for this MOE will be a 7. This corresponds to the lower end middle range score on the utility assignment criteria. The second MOE, number of lost images, was a significant attribute in both the questionnaire responses and previous studies on lost images with film-based technology at Madigan (Leckie, 1992). The utility value assigned to lost images is a 9. The third MOE, time to retrieve archival

images, showed a significant difference in both the questionnaire and in the increased number of outpatient visits. Therefore it also has a utility assignment of 9.

The next step is to weight each of the figures of merit for each measure of effectiveness. The first MOE is retakes; a weight of .2 is assigned for each figure of merit because they all have approximately equal importance to the overall system. The second MOE, lost images, has availability weighted most heavily with .3, dependability, capability, and useability weighted equally (.2) and maintainability the lowest weight (.1). The third MOE is time to retrieve historical images. Availability, dependability, and capability are all weighted equally, at .3, and a lower weight is given to maintainability and useability (.05) because these have little impact on this measure. A summary of the utility scores and weights are shown in Table 4-6 below:

Utilities	FAMC	MAMC
MOE		
Retakes (R)	5	7
Lost Images (L)	5	9
Historical (H)	5	9

Weights	R	L	H
Availability	0.2	0.3	0.3
Dependability	0.2	0.2	0.3
Capability	0.2	0.2	0.3
Maintainability	0.2	0.1	0.05
Useability	0.2	0.2	0.05

Table 4-6. Assignment of Utility and Weights

Next a total score for each figure of merit is calculated using the formula:

$$FOM_i = \frac{\sum W_j \times U_{ji}}{\sum W_j}$$

where,

FOM_j: FOM for the *i*th alternative

W_j: weight for the *j*th MOE

U_{ji}: utility assigned to the *i*th alternative with respect to the *j*th

MOE

Table 4-7 summarizes each FOM total for each alternative. The results are scored according to their relative importance and the final overall effectiveness score (E) is shown for each alternative. The final number represents the overall effectiveness divided by the life-cycle cost for each alternative.

Weights	R	L	H	FOM (FAMC)	FOM (MAMC)	Score	E(FAMC)	E(MAMC)
Availability	0.2	0.3	0.3	5.00	8.50	25.00	500.00	741.67
Dependability	0.2	0.2	0.3	5.00	8.43	30.00		
Capability	0.2	0.2	0.3	5.00	5.21	25.00	CE (FAMC)	CE (MAMC)
Maintainability	0.2	0.1	0.05	5.00	7.86	5.00	21.64	54.94
Useability	0.2	0.2	0.05	5.00	7.11	15.00		
Total				25.00	37.11	100.00		

Table 4-7. Cost Effectiveness Calculation

The results of the cost effectiveness calculation favor the digital imaging system by a factor of approximately 2.5 to 1. In terms of effectiveness per dollar invested, the digital system achieves over twice the benefit of the conventional film-based system. The primary reason for this difference is that the life cycle cost is half as much for a digital system when only maintenance and investment costs are considered. This ratio is a conservative estimate because salvage value of the system at the end of the time horizon was not considered. If salvage value was included it would increase the cost difference between the two systems, favoring the digital system. As the operational proficiency with digital imaging improves at Madigan, and reliance on a film back-up system dissipates, the operations costs will decrease significantly.

V. CONCLUSION

A. GENERAL

The MDIS system is a technological leap into the future. The MDIS system, when complete, will meet the goal of the Government's healthcare reform by improving healthcare quality and providing a more cost effective imaging system. The decreasing Federal budget and increased demand for quality warrants using cost effective state-of-the-art technology in the Department of Defense. The purpose of this study was to validate claims of improvements and extend previous studies of the system. The results are based on three measures of effectiveness: image retakes, lost images, and time to retrieve archived images. The two methods used to collect the data were questionnaires, completed by physicians who work under two different imaging technologies, and interviews with specialists in logistics, financial management, patient administration, and information management at each facility.

The sites chosen for the study included Madigan Army Medical Center and Fitzsimons Army Medical Center. Madigan is the first medical treatment facility within the Department of Defense to receive the MDIS system. It was compared with the baseline alternative, Fitzsimons, which represents a typical film-based imaging system. Although each facility supports a different population, they are similar in terms of regional area mission responsibilities.

The questionnaire results were consolidated and recorded as frequency data. Interview data were used in the spreadsheets, tables, and graphs. A modified life cycle cost was developed for each system using capital investment and maintenance costs. A utility function was developed for each MOE based on quantitative and qualitative evaluation of the data. Finally an effectiveness score was calculated for each imaging system.

B. SUMMARY OF RESULTS

The overall questionnaire results showed that physicians completing the questionnaire slightly favored digital imaging technology. This limited difference was not surprising, however. Madigan was the first operational system user. The throughput rate for retrieving images is not yet fast enough for the radiologist to meet the proper diagnosis rate. Under a film based system, a radiologist can make a diagnosis every 90 to 180 seconds (Bender, 1994). As a result, Madigan uses digital imaging with a film-based back-up system. It runs a dual technology radiology imaging system. The system users' expectations were too high as a result of promised capability that has yet to materialize. For example, the system is not yet integrated with the magnetic resonance imaging system. Although digital images are obtained, they are not yet networked within the MDIS system. Many software upgrades have been installed causing some system downtime and inconvenience to the users. The implementation schedule has slipped significantly due to system integration, software, and requirement changes.

C. RESEARCH QUESTIONS

The primary research question is: Are there cost effectiveness differences between the state-of-the-art digital imaging system and the traditional film-based imaging technology most frequently used by Government and civilian medical treatment facilities? In the final cost effectiveness calculation, the digital imaging technology provided greater benefits than film-based imaging technology by a ratio of 2.54 to 1. This means that the benefits per dollar investment for the MOEs used in this study are roughly two and a half times greater for digital imaging than film. The difference is large because the technology is more effective and it is also cheaper. This ratio is a conservative estimate because salvage values at the end of the seven year life span were not considered. Obviously, the new system would have a greater salvage value than the old system at the end of its expected life. Therefore, the digital imaging technology provides more than twice the benefit of the film-based system and is also cheaper.

not a significant difference in the answers provided in the questionnaire from the two sites. However, a trend analysis of the retake data provided by the Madigan Radiology Department suggest that in the future the result could become significant as technicians learn to use the digital system more effectively.

The subsidiary research question that addresses differences in the number of lost images favored digital imaging. There was a 10% difference of questionnaire responses between Madigan and Fitzsimons, pertaining to lost images, that favored digital technology verses film. The qualitative issues associated with lost images including: incorrect treatment, delayed diagnosis, increased exposure as a result of retakes, and decreased productivity in clinics make digital imaging superior to film-based imaging.

The third subsidiary question addressed time to retrieve archived images. The results of the questionnaire clearly show that physicians can retrieve archived images faster under a digital imaging system. It remains unclear whether this time saving tool improves physician efficiency. The qualitative issues associated with this MOE, such as time to diagnosis and treatment, strongly favor digital imaging.

The fourth subsidiary question addresses effectiveness per investment dollar. The denominator in this approach is the life cycle cost of the system. The large cost differences between the two systems is explained by two primary factors. First, the new system has very little replacement equipment cost in the seven year time horizon used in the modified life-cycle calculation. Further, the MDIS equipment has a one year warranty period built into the contract, during which there are virtually no maintenance costs. Second, the older system requires high capital investment to replace old equipment and to modernize outdated equipment within the Radiology Department. The fiscal year 1993 new equipment costs at Fitzsimons, under the MEDCASE program, were roughly \$5.2 million. However, in keeping with conservative estimates, only a \$4.0 million annual capital equipment cost was used in the life-cycle calculation.

D. AREAS FOR FURTHER RESEARCH

There are many opportunities for improving the Department of Defense medical system under the Government's National Healthcare Reform initiatives. The Military Services, in a joint effort, need to reengineer clinical practices in medicine, with affordability as the over-arching goal (Jenkins, 1995). Seeking technology with dual-use capability between civilian and military healthcare systems decreases development and production costs. The MDIS system is a step toward meeting the goals of these initiatives. This study looked at whether digital imaging improves image retake rates, decreases lost images, and decreases the time spent retrieving archived images. However, there are many other applications associated with digital imaging that are yet to be measured in terms of cost, benefits, and effectiveness. When all phases of the system are integrated within and between facilities these applications will include:

- Computer-Aided Diagnosis
- Real-time Image Interpretation
- Teleradiology
- Continuing Medical Education

Researchers at the University of Chicago are studying computer-aided diagnoses for radiologists. They built a limited database of patient case files and compared the radiologist's diagnoses with computer generated diagnoses. They found that the computer diagnosis came up with a high false negative rate. But when the computer provided assistance to the radiologist, there was a significant decrease in the number of missed diagnoses. (Kunio, 1995) Computer-aided diagnosis has tremendous potential for improving the quality of patient care, but cost benefit and cost effectiveness has yet to be determined.

The ideal Radiology Department could interpret images in real-time. This time saving technique results in quicker diagnosis and treatment and may preclude unnecessary return visits by patients. Some improvements to the current system must be implemented

before this can be accomplished. One example is increased luminescence to achieve diagnostic quality images. Radiology Departments may be able to reassign radiologists to specific areas (e.g. Department of Surgery, Orthopedics, Emergency Room) to facilitate real-time image interpretation.

The teleradiology portion or phase III of the MDIS implementation schedule will link several medical treatment facilities from all Services in a project called Seahawk. The project goals include increased efficiency through teleconferencing, a corresponding decrease in patient referrals to other facilities, and improved quality of patient care by providing faster Services.

An application of MDIS is developing teaching files for residents and continuing medical education for physicians. This benefit is difficult to measure in terms of cost but increases the quality of patient care which can be quantified in future studies.

E. SUMMARY

The MDIS system holds promise for reengineering healthcare in the military. The cost effectiveness of the system is demonstrated in this as well as previous studies. The MDIS system overcomes many of the limitations of film-based technology, including: the ability to examine an image at one location at a time, efficiently transfer images from one location to another digitally, and overcoming the 20-40% loss rate experienced in many large medical treatment facilities. There are some problems with the technology which also must be overcome, including producing a diagnostic quality image for radiologists, establishing an interface architecture with commercial radiology systems such as magnetic resonance imaging, and establishing realistic expectations for system performance. As the technology matures, the third-order benefits defined by Malone and Rockart, 1991 will evolve making the system more effective in the future.

APPENDIX A



IMAGING SURVEY



This survey evaluates four aspects of medical imaging in your facility.
The four areas to be assessed are:

- Frequency and reasons for image retakes
- Consequences of lost images
- Reasons and frequency of lost images
- The time to retrieve archival images

Please take a moment to complete this survey. Your responses will be used to evaluate the costs and benefits of two imaging technologies.

Circle the letter which best answers the questions below:

1. How many times a month does your department, ward, or clinic request archival images from the records storage area within your facility?

- a. 0-35
- b. 36-70
- c. 71-100
- d. greater 100
- e. don't know

2. On the average, how much time does it take to retrieve an image from your organizations record storage location?

- a. 10 minutes
- b. 30 minutes
- c. 1-2 hours
- d. more than 2 hours
- e. don't know

3. What percent of archival images are not available when requested by a clinician?

- a. less than 5%
- b. 5-10%
- c. 10-20%
- d. greater than 20%
- e. don't know

4. What percent of patient images require retakes?

- a. less than 1%
- b. 1-5%
- c. 5-10%
- d. greater than 10%
- e. don't know

5. Of the personnel listed below, place a number from 1 to 5 in the boxes to indicate the person who most frequently retrieves images from the image storage room? (1 indicates most frequent and a 5 indicates least frequent.)

Clerk ☐ Technician ☐ Nurse ☐ Physician ☐ Other ☐

Please take a moment to write your response in the space provided:

6. From the most serious to least serious, list the 5 most severe consequences of lost images in your department.

- (1) _____
- (2) _____
- (3) _____
- (4) _____
- (5) _____

7. From the most frequent to least frequent, list the 5 most common causes of lost images within your facility.

- (1) _____
- (2) _____
- (3) _____
- (4) _____
- (5) _____

8. Additional Comments:

Fill in the appropriate information:

NAME (Optional) _____

POSITION _____

RANK/GRADE _____

DEPT/CLINIC/WARD _____

Circle your response:

Are you willing to discuss this survey in a follow-on interview? YES NO

If yes, to previous question please provide duty phone number in the space provided: _____

APPENDIX B

QUESTIONNAIRE RESULTS

MAMC

FAMC

How many times do you request an image from the storage area within your facility?													
Possible resp.	0-35	36-70	71-100	>100	Don't know	SUM	Possible resp.	0-35	36-70	71-100	>100	Don't know	SUM
QUESTION 1	A	B	C	D	E	SUM	QUESTION 1	A	B	C	D	E	SUM
FREQUENCY	18	11	5	15	9	58	FREQUENCY	17	8	2	7	2	36
PROBABILITY	0.31	0.19	0.09	0.26	0.16	1	PROBABILITY	0.47	0.22	0.06	0.19	0.06	1
CUM PROB	0.31	0.50	0.59	0.84	1.00		CUM PROB	0.47	0.69	0.75	0.94	1.00	
On the average, how much time does it take to retrieve an image from your storage location?													
Possible resp.	10 min	30 min	1-2 hrs	>2 hrs	Don't know	SUM	Possible resp.	10 min	30 min	1-2 hrs	>2 hrs	Don't know	SUM
QUESTION 2	A	B	C	D	E	SUM	QUESTION 2	A	B	C	D	E	SUM
FREQUENCY	27	17	4	1	9	58	FREQUENCY	1	7	9	15	4	36
PROBABILITY	0.47	0.29	0.07	0.02	0.16	1	PROBABILITY	0.03	0.19	0.25	0.42	0.11	1
CUM PROB	0.47	0.76	0.83	0.84	1.00		CUM PROB	0.03	0.22	0.47	0.89	1.00	
What percent of archival images are not available (lost) when requested by a clinician?													
Possible resp.	<5%	5-10%	10-20%	>20%	Don't know	SUM	Possible resp.	<5%	5-10%	10-20%	>20%	Don't know	SUM
QUESTION 3	A	B	C	D	E	SUM	QUESTION 3	A	B	C	D	E	SUM
FREQUENCY	17	6	10	9	16	58	FREQUENCY	6	12	8	6	4	36
PROBABILITY	0.29	0.10	0.17	0.16	0.28	1	PROBABILITY	0.17	0.33	0.22	0.17	0.11	1
CUM PROB	0.29	0.40	0.57	0.72	1.00		CUM PROB	0.17	0.50	0.72	0.89	1.00	
What percent of patient images require retakes?													
Possible resp.	<1%	1-5%	5-10%	>10%	Don't know	SUM	Possible resp.	<1%	1-5%	5-10%	>10%	Don't know	SUM
QUESTION 4	A	B	C	D	E	SUM	QUESTION 4	A	B	C	D	E	SUM
FREQUENCY	7	21	17	4	9	58	FREQUENCY	4	11	11	3	7	36
PROBABILITY	0.12	0.36	0.29	0.07	0.16	1	PROBABILITY	0.11	0.31	0.31	0.08	0.19	1
CUM PROB	0.12	0.48	0.78	0.84	1.00		CUM PROB	0.11	0.42	0.72	0.81	1.00	

Of the personnel listed below, who retrieves images most often?													
QUESTION 5	CLERK	TECH	NURSE	DOCTOR	OTHER	(other write-in)	QUESTION 5	CLERK	TECH	NURSE	DOCTOR	OTHER	(write-in)
no response	26	28	33	12	42	PA	no response	11	18	21	14	20	Intern
1	8	7	0	35	2	Computer (2)	1	13	4	2	8	7	NCO
2	5	12	1	6	3	Patient	2	7	6	0	7	2	Patient
3	11	3	4	3	1		3	1	7	0	4	1	
4	3	4	11	1	3		4	2	1	7	1	3	
5	4	4	9	1	7		5	2	0	6	2	3	

QUESTION 6 From the most serious to least serious, list the 5 most severe consequences of lost images in your department.

Response	Frequency	
	MAMC	FAMC
Delayed diagnosis and treatment	27	20
Retake image	13	19
Increase time and money	7	6
Patient dissatisfaction	11	7
Physician frustration	12	4
Unable to compare studies	8	4
Poor patient care	9	7
Legal cost	3	3
Death	2	3
Increased exposure	6	4
Cancel/wrong surgery	1	1
Increase hospital stay	1	1
Increase clinic wait	6	1
Increase patient risk	0	1
Missed diagnosis	0	5
Wrong treatment	9	0
Poor institutional image	1	0

QUESTION 7 From the most frequent to least frequent, list the 5 most common causes of lost images within your facility

Response	Frequency	
	MAMC	FAMC
Black hole, the \$64,000 question	5	5
MDIS down	7	0
Wrong jacket	1	0
Poor film	1	0
Physician take	9	13
Misplaced	1	1
Consultants take	1	0
Lost in MDIS	3	0
Patients Take	1	4
Misfile	8	13
Clinic takes	1	1
X-rays not read by radiologist	1	0
Film made into teaching file	1	0
Tech does not put on system	1	1
Not ordered	1	0
Doesn't happen	1	0
Confusion	0	1
Wards take	0	1
Lost in transit	0	1
Mislabeled	0	1

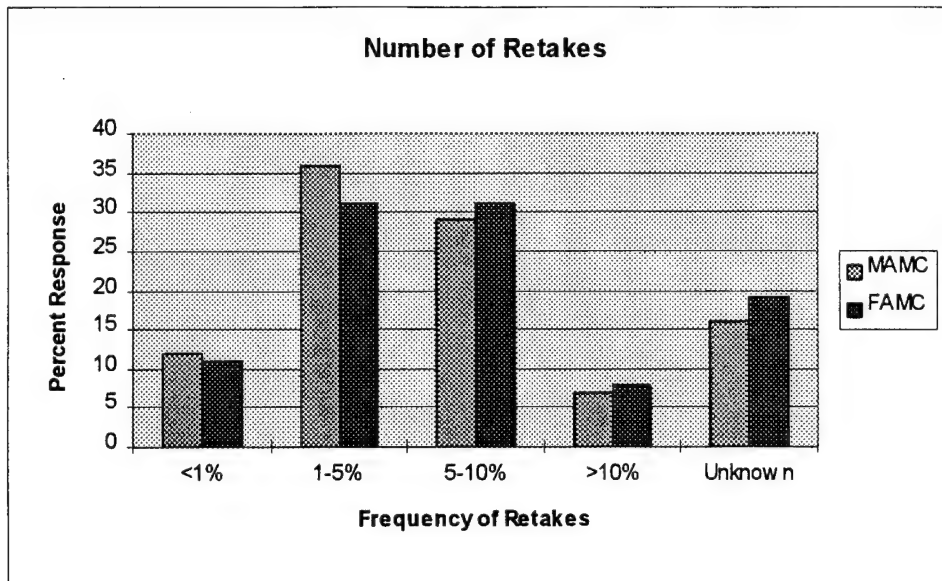
QUESTION 8 Additional Comments

MAMC
<ol style="list-style-type: none">1. Most of the images are on computer so they are not lost.2. With the MDIS system, film retrieval is far easier than facilities without MDIS.3. You should define your terms before asking questions.4. The system (MDIS) is not reliable.5. Need longer times before station signs off during clinic hours.6. Most of the time there are no serious problems with MDIS since retrieval of the image is available all the time.7. The only way to get the important studies (CXR, bone films) is to ask the patient to bring the unread wet film back, and hand carry to radiologist for diagnosis.8. We need an MDIS terminal in oncology.9. Still patiently awaiting MDIS for HEME/Onc section.10. If MDIS is the answer to this, we are extremely frustrated by still not having a single MDIS workstation in the clinic

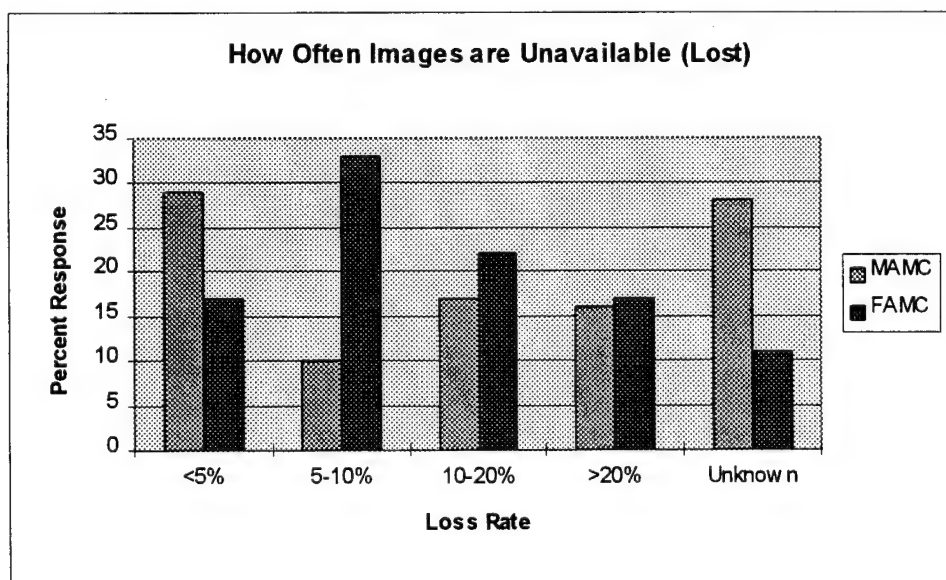
FAMC
<ol style="list-style-type: none">1. I really would like to retrieve films on weekends, is this possible?2. Easy access to timely written reports would be more helpful than access to film.3. Mortise views in cast are most common cause of retakes.4. Often times quality of images is not adequate- rotated views accepted by technicians require reordering- cause clinic delays.

The following bar charts show a comparison of each medical treatment facility's questionnaire results.

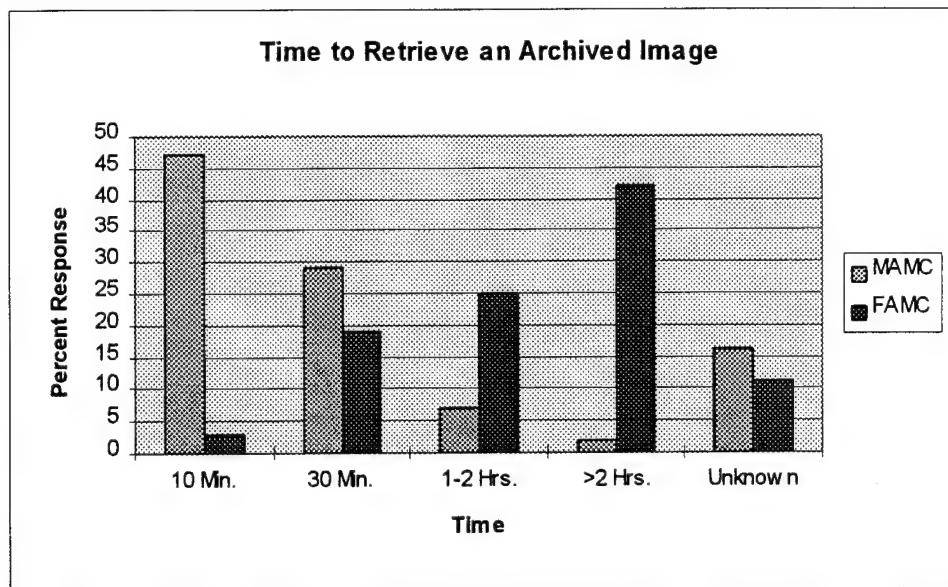
What percent of patient images require retakes?



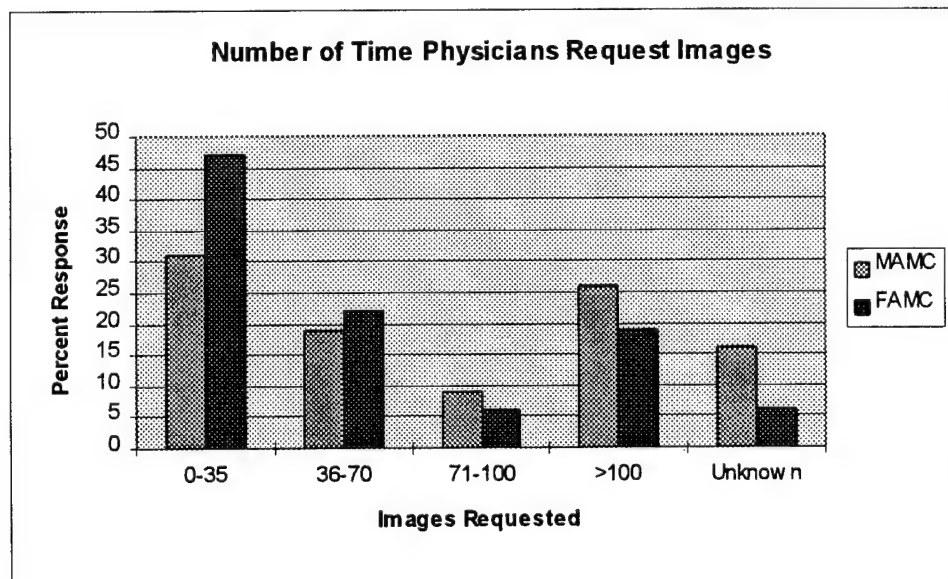
What percent of archival images are not available (lost) when requested by a physician?



On the average, how much time does it take to retrieve an image from your storage location?



How many times do you request an image from the storage area within your facility?



APPENDIX C

INTERVIEW INSTRUCTIONS

My name is Major Tracey Syvertson, I am an Army Medical Service Corps officer assigned to the Naval Postgraduate School. I am doing a study which compares two different imaging technologies at Madigan and Fitzsimons Army Medical Centers. I would like to ask you specific questions that will be used in my research project. Will you assist me in this regard? If you would like to preserve your anonymity, I will withhold your name from the study and quote only your title.

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